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The US Navy's Current and Future Sea Ice Forecast Capabilities using CICE

Ruth H. Preller, Richard A. Allard, Alan J. Wallcraft and Pamela G. Posey
along with a host of others

CICE Consortium Workshop
26-27 October 2016, Santa Fe, NM

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Outline

- Navy's use of CICE
- Historical/current operational and pre-operational capabilities
- Data assimilation
- Ice products used in mission support
- Ongoing work
- Future capabilities
- Future plans and technical CICE challenges

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Navy's Use of CICE

- Navy uses CICE as part of their prediction systems to forecast ice cover characteristics (Arctic and Antarctic)
- Forecasts were originally required on scales of days to a week, more recently the Navy requirements include seasonal forecasts
- Forecasts are currently provided by coupled ocean-ice system that assimilates real-time satellite ice concentration data
- Forecasts are currently at resolutions of 3-4 km, soon to be upgraded to 2 km, with a goal of even higher resolution (~1 km) in the next few years
- CICE is part of the Navy's global coupled Atmosphere-Ocean-Ice-Wave "Earth System Prediction Capability - ESPC"

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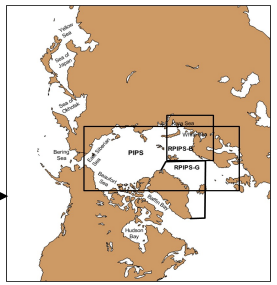
Sea Ice Prediction at NRL

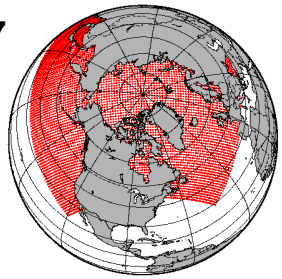
1980's

- 1984: Began work Hibler ice model and monthly mean ocean
- 1987: Polar Ice Prediction System (PIPS)* 127 km res
- 1989: Regional PIPS* 25 km res (Greenland & Barents)



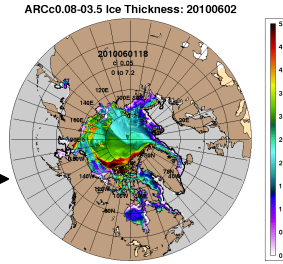
1990's

- 1991: Began coupled work Hibler ice and Cox ocean models
- 1993: DMSP SSMI initialization of ice concentration
- 1996: PIPS 2.0* 27 km horizontal res 15 vertical layers



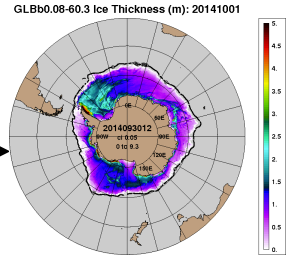
2000's

- 2003: PIPS 2.0* transitioned from FNMOC to NAVO
- 2006: Began coupled HYCOM/CICE for Arctic region 3.5 km horizontal res/ 32 and 41 vertical layers (ACNFS and GOFS 3.1 respectively)

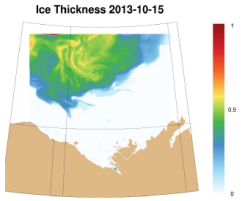


2010's

- 2013: 1/12⁰ Arctic Cap Nowcast/Forecast System (ACNFS)*
- 2015: 1/12⁰ Global Ocean Forecast System (GOFS) 3.1
- 2017: 1/25⁰ GOFS 3.5 w/tides
- 2018: 1/12⁰ ESPC demo



- 2019: Began fully coupled work Earth System Prediction Capability (ESPC) (Air/Ocean/Ice/Waves/Land)
- GCOM-W1 AMSR2 initialization of ice concentration
- Regional Air/Ocean/Ice in COAMPS



***System Transitioned/ Operational**

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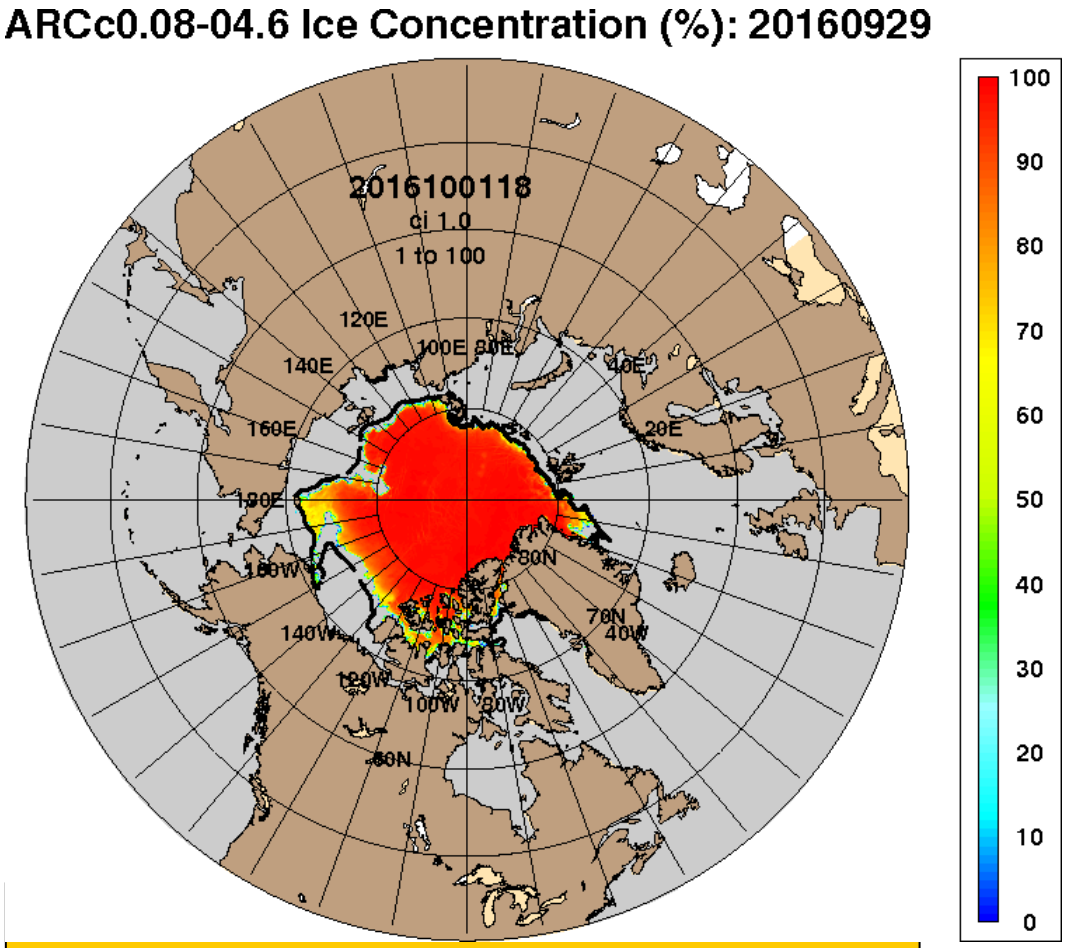
Arctic Cap Nowcast/Forecast System (ACNFS)

- ACNFS consists of 3 components:
  Ice Model: Community Ice CodE (CICE) v4
  Ocean Model: HYbrid Coordinate Ocean Model (HYCOM)
  Data assimilation: Navy Coupled Ocean Data Assimilation (NCODA)
- Prescribed atmospheric forcing from NAVy's Global Environmental Model (NAVGEM)
- Declared operational Sept 2013
- Runs daily at the Naval Oceanographic Office (NAVOCEANO)
- ACNFS produces nowcast/7-day forecasts of ice concentration, ice thickness, ice drift, SST, SSS and ocean currents for the Northern Hemisphere
- Products pushed daily to the U.S. National Ice Center (NIC) and NOAA

Daily graphics can be found:
www7320.nrlssc.navy.mil/hycomARC



Black line is the independent ice edge location (NIC). Animation spans Sept – Oct 2016

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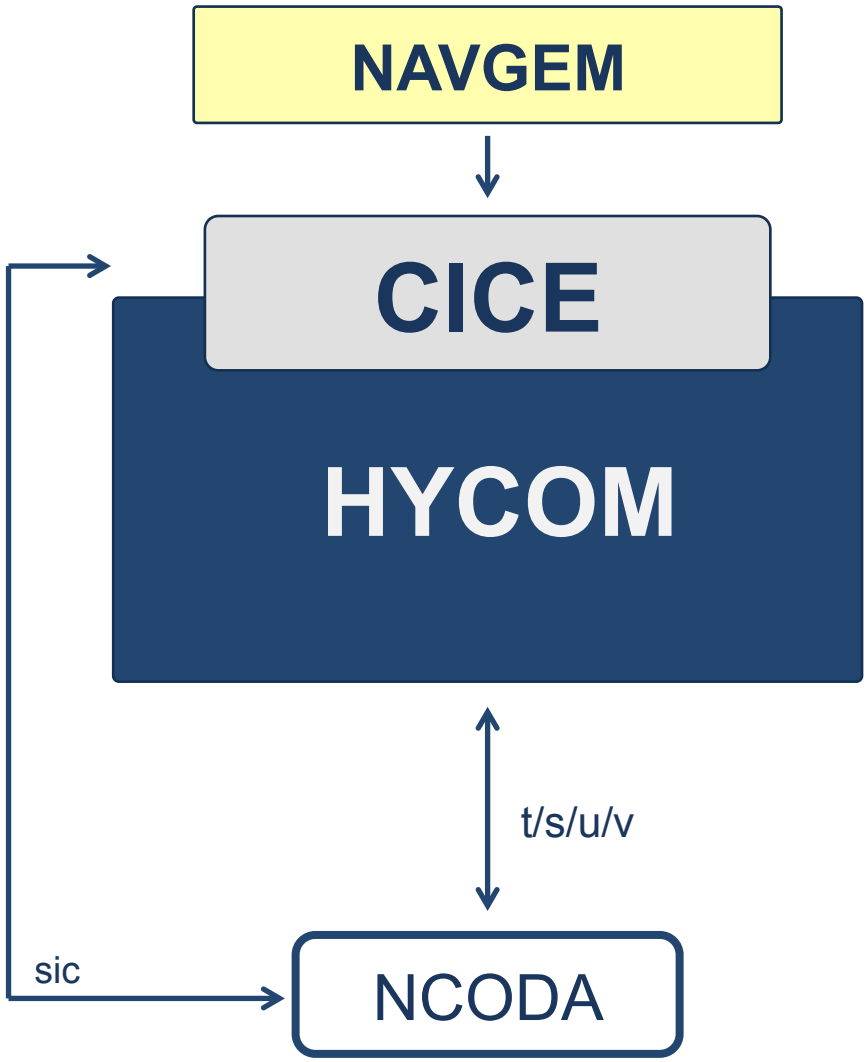
Global Ocean Forecast System (GOFS) 3.1

- **Metzger et al. (2014), *Oceanography***
- **Ocean Model:**
  - HYbrid Coordinate Ocean Model (HYCOM) (DoD)
  - 0.08° (~9 km near equator, ~7 km at mid-latitudes)
  - 41 vertical hybrid layers
- **Sea Ice Model:**
  - Community Ice CodE (CICE v4) (DOE)
  - 0.08° (~3.5 km at North Pole)
- **Ocean/Ice Data Assimilation:**
  - NCODA
  - 3DVar
  - 24 hour update window
  - Cummings and Smedstad (2013) in *Data Assim for Atmos, Ocean & Hydro Applications*
- **Pre-Operational**
  - 7 day forecasts
  - Atmospheric boundary forcing supplied by NAVGEM
  - Will replace ACNFS when operational



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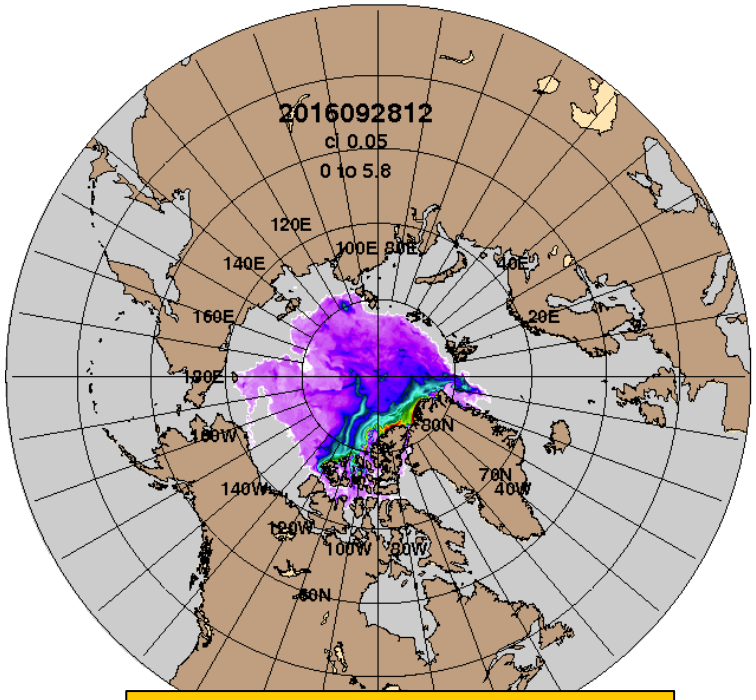
Global Ocean Forecast System (GOFS) 3.1

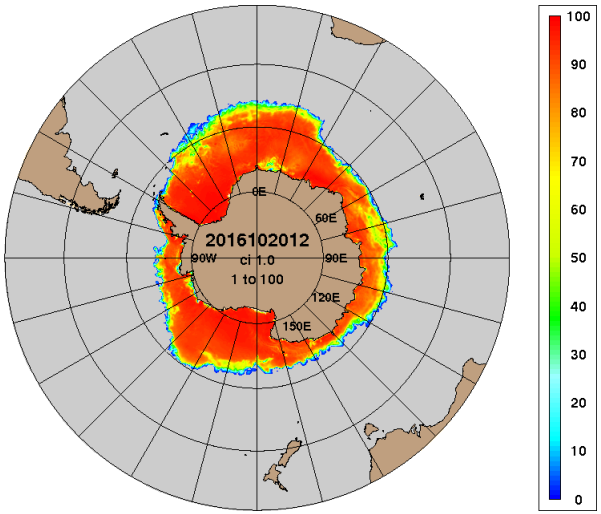
- Similar to ACNFS, GOFS 3.1 produces ice forecasts in the Northern Hemisphere and also has the added capability of forecasting ice conditions in the southern hemisphere.

Daily graphics available:
http://www7320.nrlssc.navy.mil/GLBhycomcice1-12

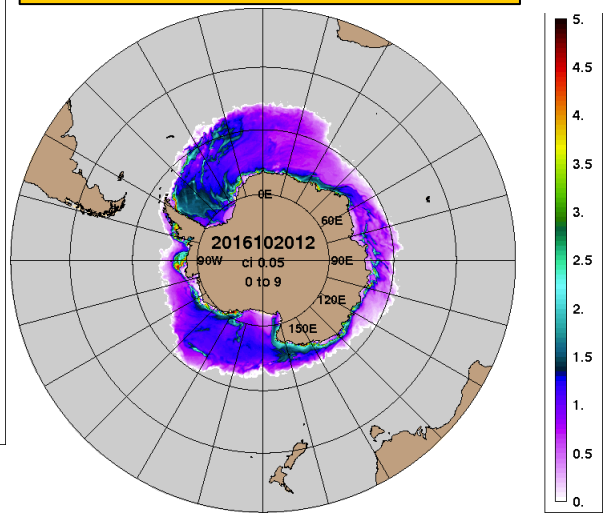
GLBb0.08-92.7 Ice Thickness (m): 20160929



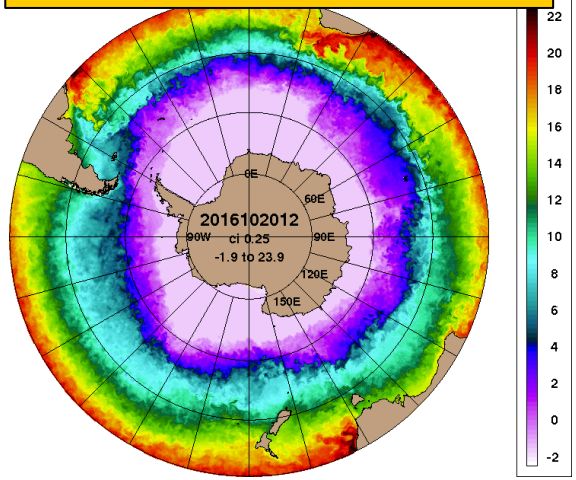
GOFS 3.1 Ice Concentration
Valid 20161021



GOFS 3.1 Ice Thickness
Valid 20161021



GOFS 3.1 Sea Surface Temp
Valid 20161021



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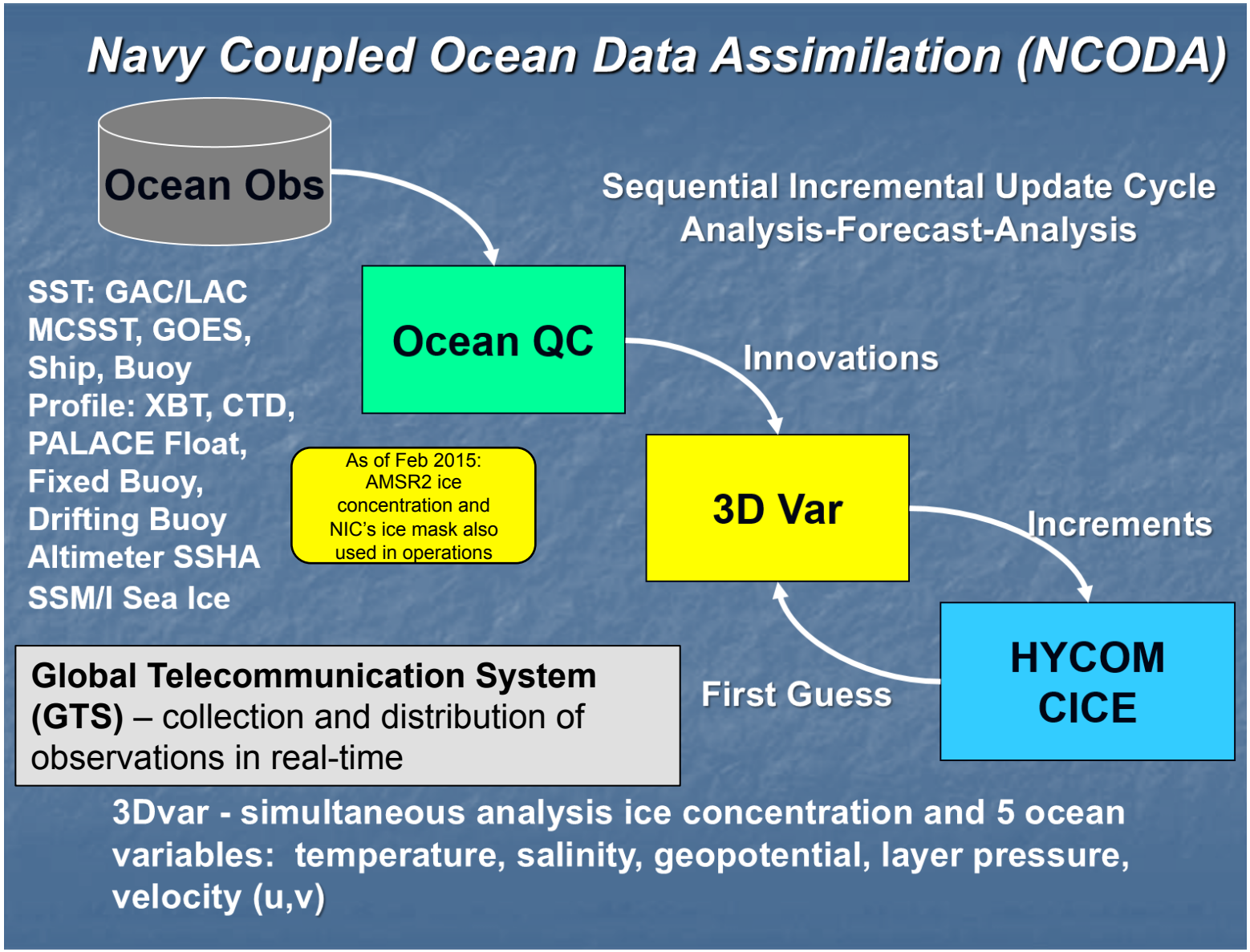
Observations Used in the Navy's Assimilation Scheme



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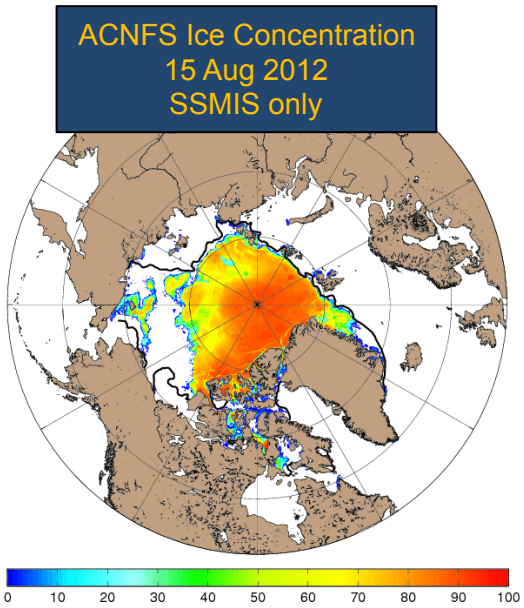
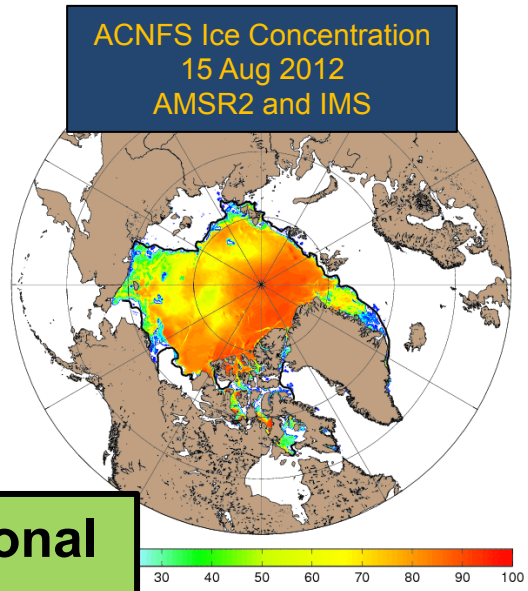
Assimilating ice observations

- Since the late 1990's, DMSP SSMI and then SSMIS ice concentration (~25km) have been assimilated in the Navy's ice forecast systems
- More recently, AMSR2 (~12.5km) has become available in real-time
- Passive microwave sensors have a known problem with underestimating sea ice during the summer
- Collaborated with NSIDC to develop technique to assimilate AMSR2 and NIC's Interactive Multisensor Snow and Ice Mapping System (IMS) ice mask (4km)
- Adding in AMSR2 and IMS, overall ice edge errors in the Arctic were reduced by ***36%*** and ***56%*** (year and summer, respectively)
- Findings documented:
  Posey et al., 2015, *The Cryosphere*
  Hebert et al., 2015, *JGR-Oceans*





Implemented new real-time data feeds into operational ACNFS and pre-operational GOFS 3.1 in Feb 2015

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Navy's Use of Ice Predictions

- Both the operational ACNFS and pre-operational GOFS 3.1 are run daily by the U.S. Naval Oceanographic Office (NAVOCEANO)
- Products from these systems are sent by NAVOCEANO to the National Ice Center (NIC) and NOAA daily
- Graphical products are also available on the NRL website:

  https://www7320.nrlssc.navy.mil/hycomARC/ (ACNFS)

  http://www7320.nrlssc.navy.mil/GLBhycomcice1-12 (GOFS 3.1)

- The NIC interacts directly with NRL to develop useful guidance products
- NRL also provides products requested by the Navy for special missions

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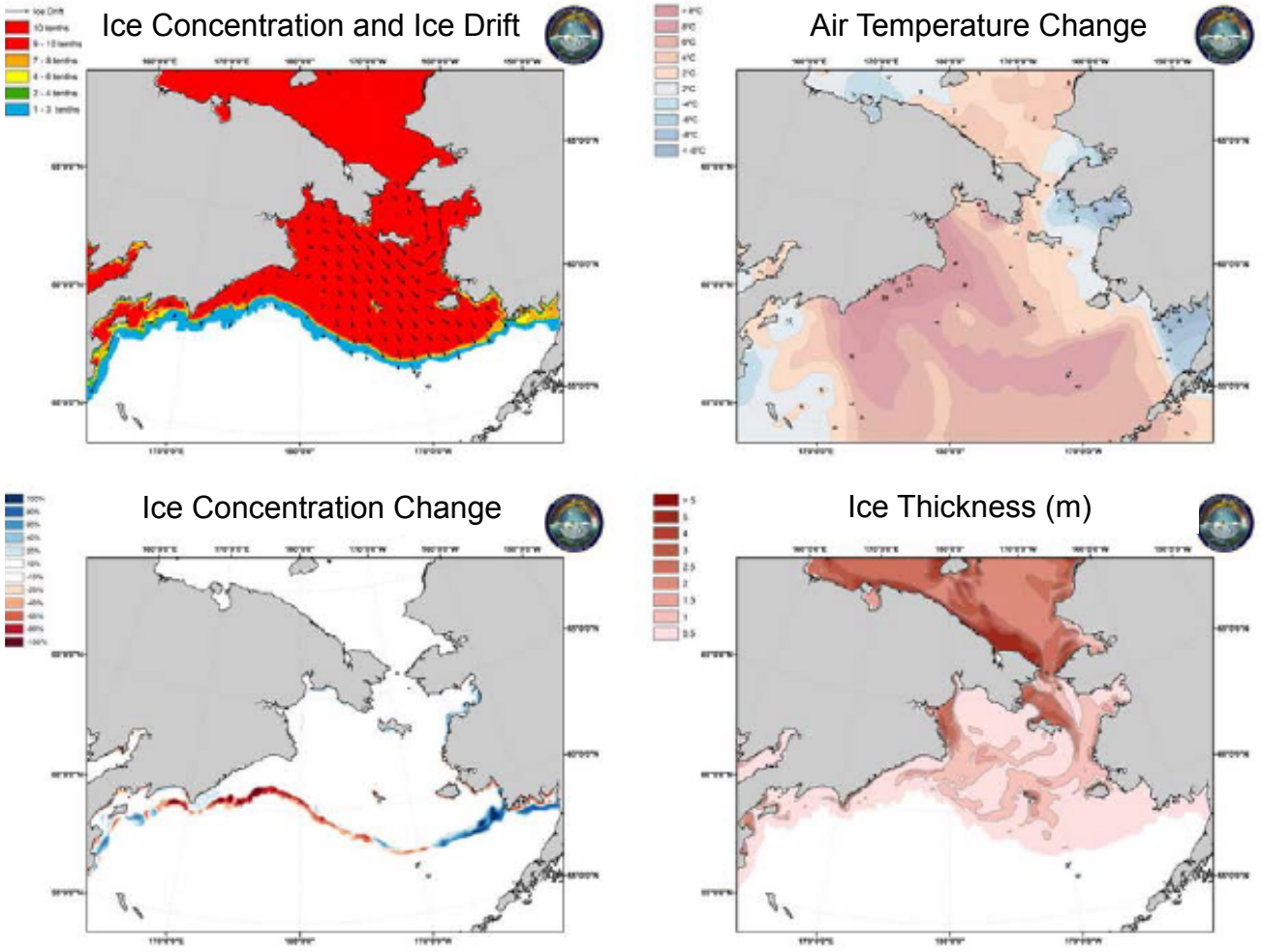
Common ACNFS Fields Used by USNIC

- Surface Winds
- Mean Sea Level Pressure
- Surface Air Temperature
- Sea Surface Temperature
- Sea Ice Fraction
- Sea Ice Thickness
- Ice Drift
- Lead Area Opening Rate
- Sea Surface Salinity
- Compressive Strength
- Freeze/Melt Potential
- Congelation Ice Growth
- Lateral Ice Melt
- Basil Ice Melt
- Surface Snow Thickness
- Surface Albedo (where ice)
- Rainfall rate
- Surface Temp (where ice)

ACNFS Ice Forecast for 2014-03-18 0000 UTC +048HR



7-day Forecast [t000-t168]

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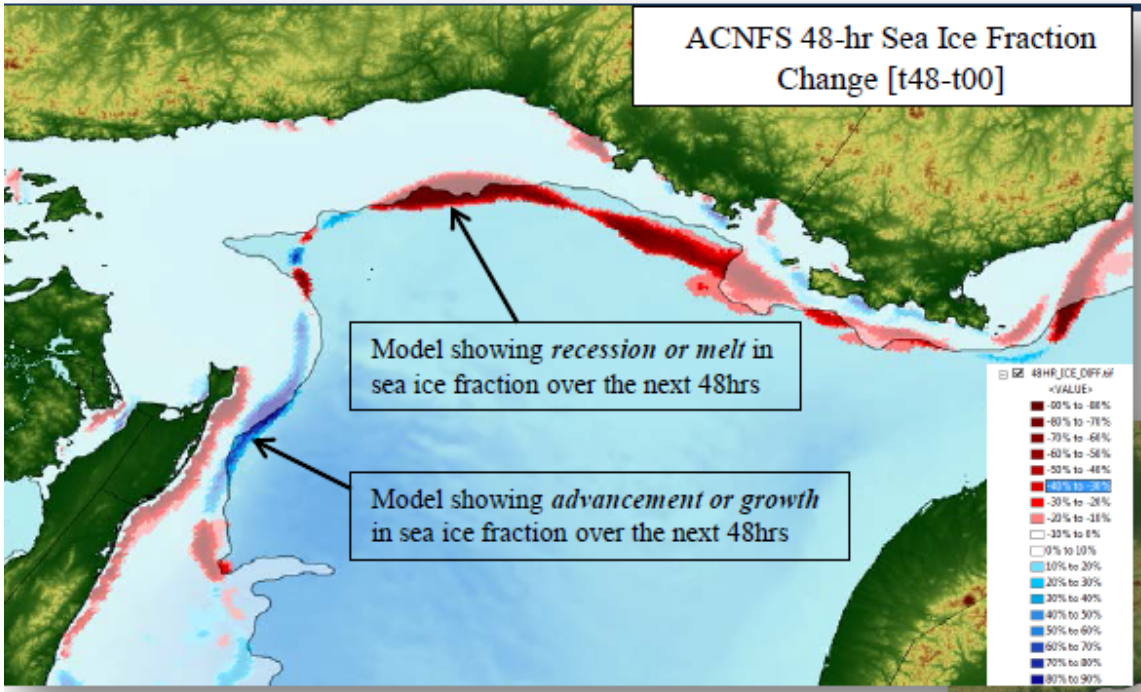
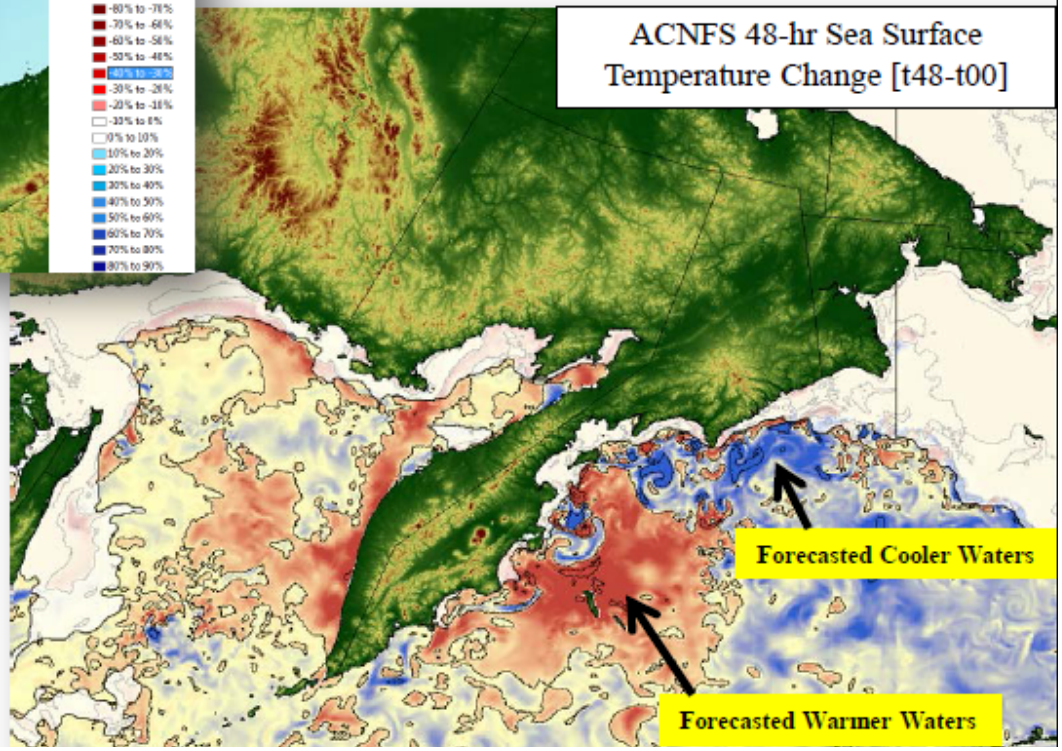
ACNFS Difference Fields



Change detection from ACNFS

- Produce 1-7 day difference fields
- Difference layers more precise and uniform
- Can be difficult to visually interpolate small differences
- Less prone to interpolation errors



Slide Courtesy of NIC

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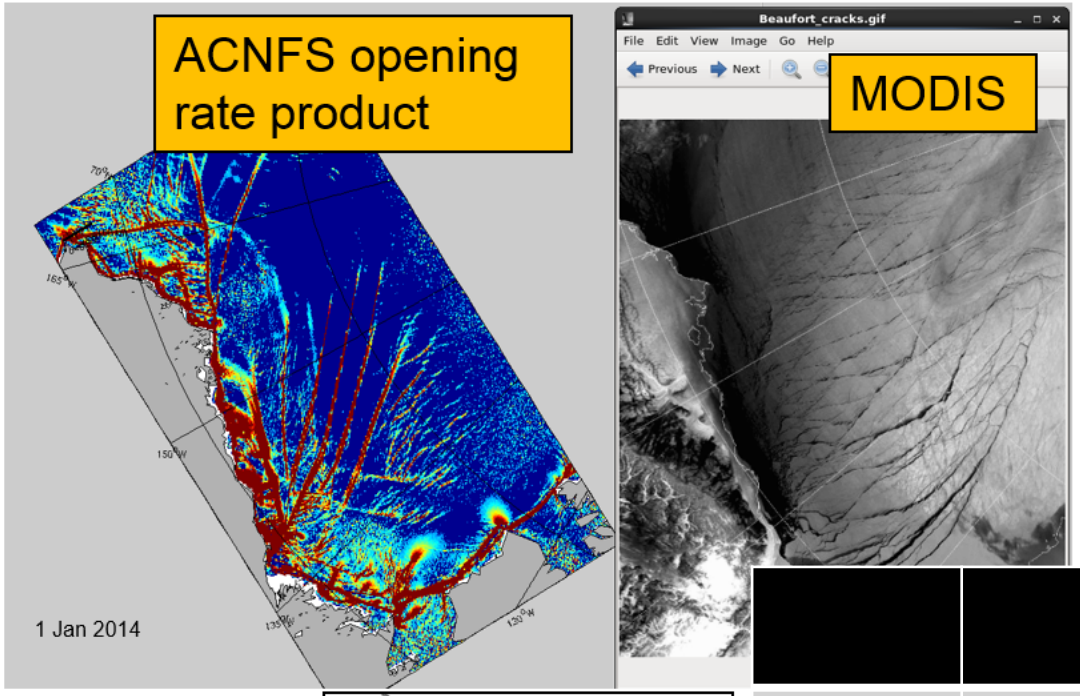
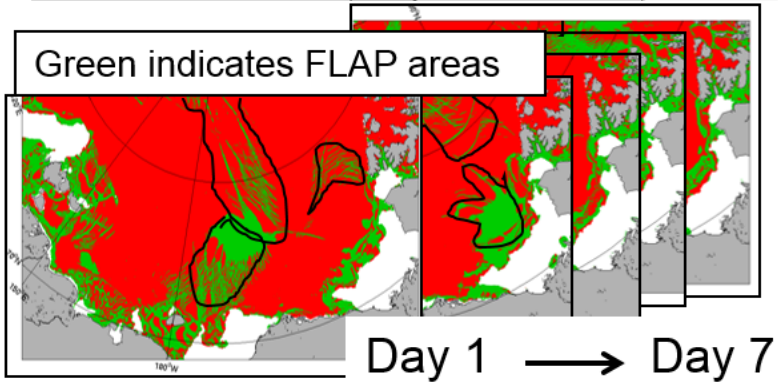
Fractures, Leads and Polynyas (FLAPs)





- FLAPs are provided to SUBFOR prior to/during Arctic transit
- Needed when surfacing for communications and emergencies
- NRL validated ACNFS/GOFS 3.1 ability to predict FLAPs-like products
- Compared to 1 year of FLAPs messages
- Declared operational Oct 2015

	Percent of Fracture Regions						
	HIT	**<> - Near Hit**				**/<>**	**MISS X**
		Off-set	Partial	Subset	Weak		
ACNFS	31%	5%	21%	22%	9%	88%	12%
		57%					
GOFS 3.1	26%	4%	21%	18%	10%	79%	21%
		53%					
ACNFS (3 days accum product)	40%	3%	10%	40%	4%	97%	3%
		57%					

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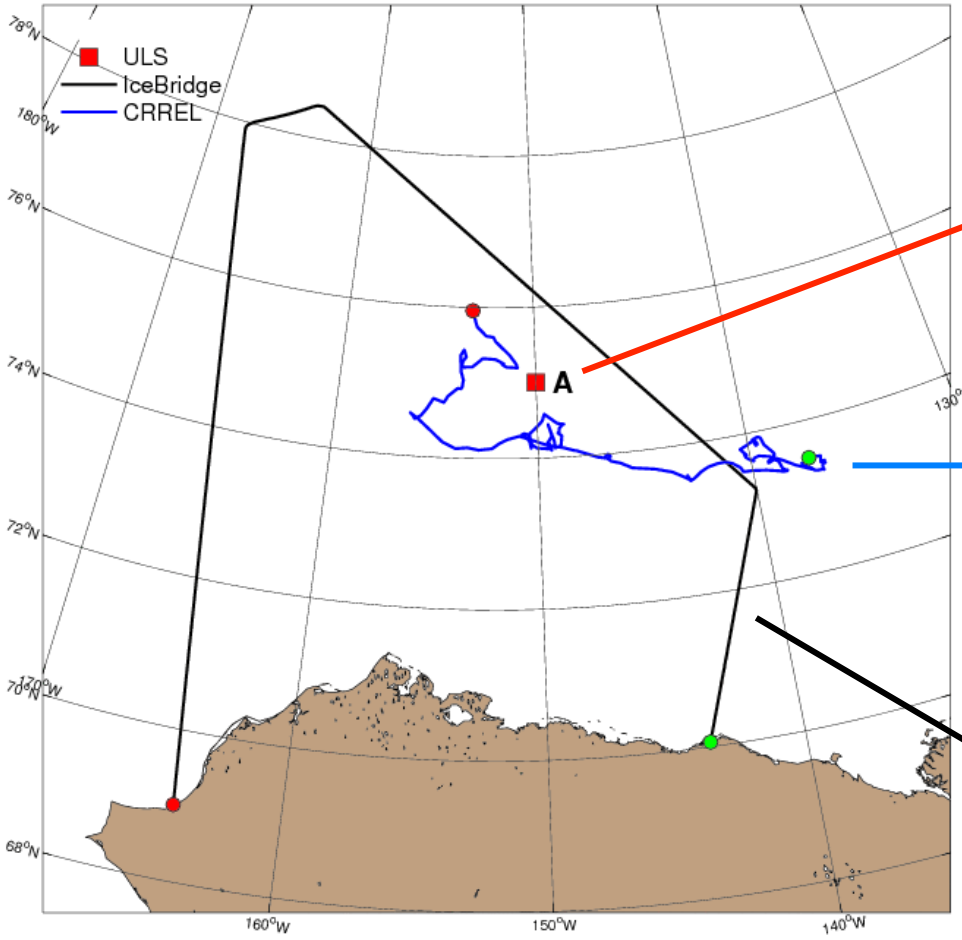
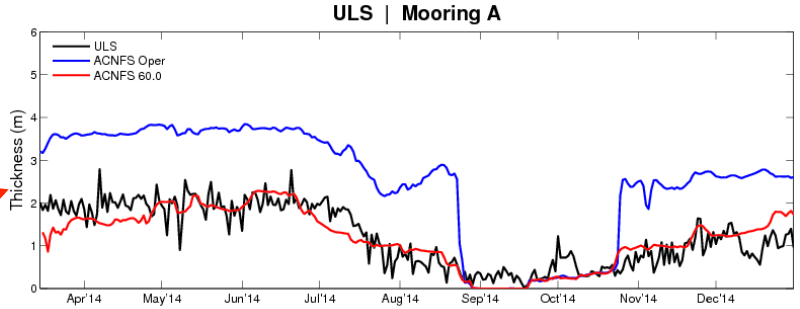
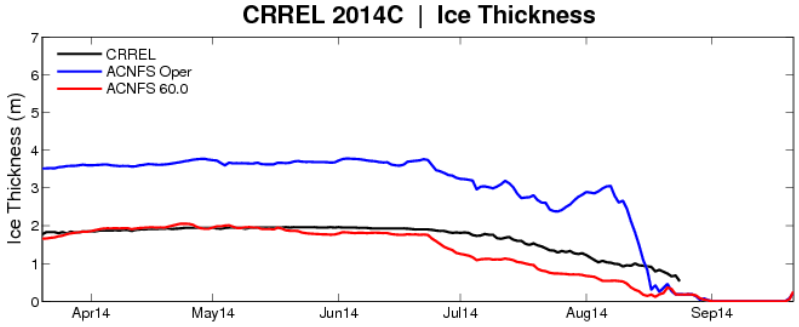
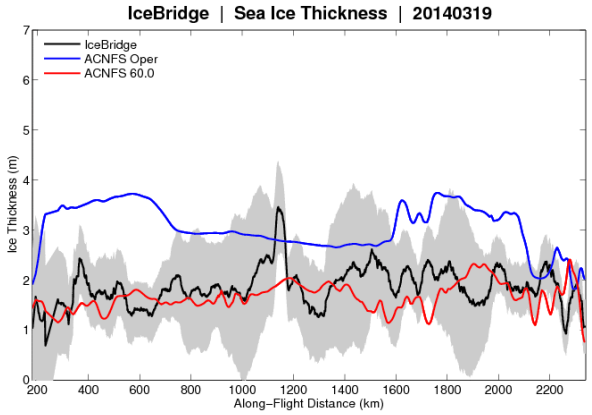
Improved Ice Thickness: ACNFS Assimilated Monthly Mean CryoSat-2/SMOS on March 15, 2014









Much improved ice thickness with blended product compared to ULS moorings, CRREL IMB and NASA IceBridge

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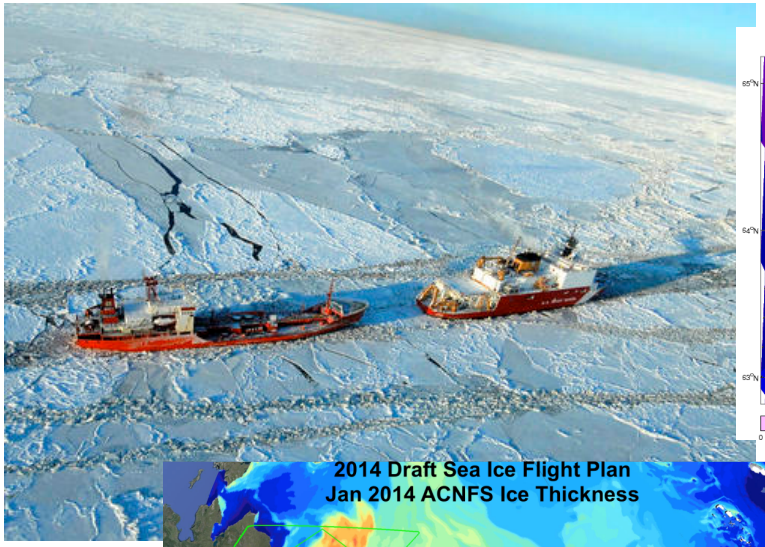
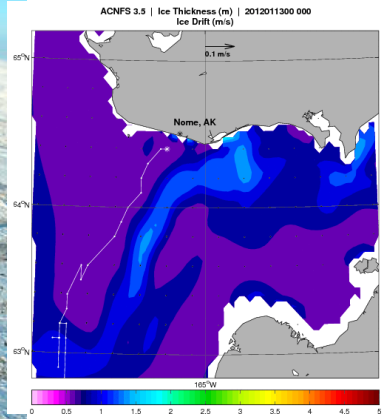
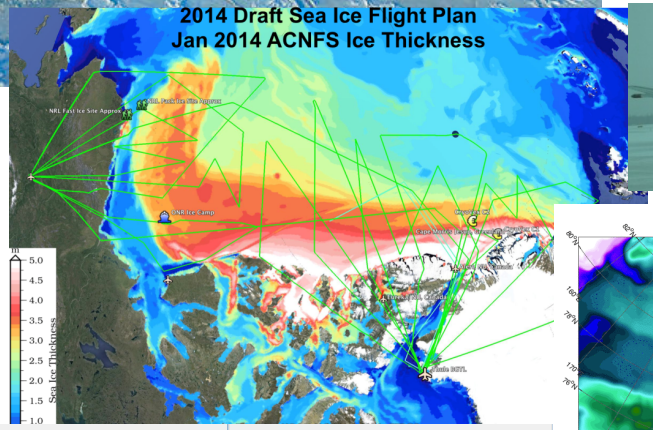
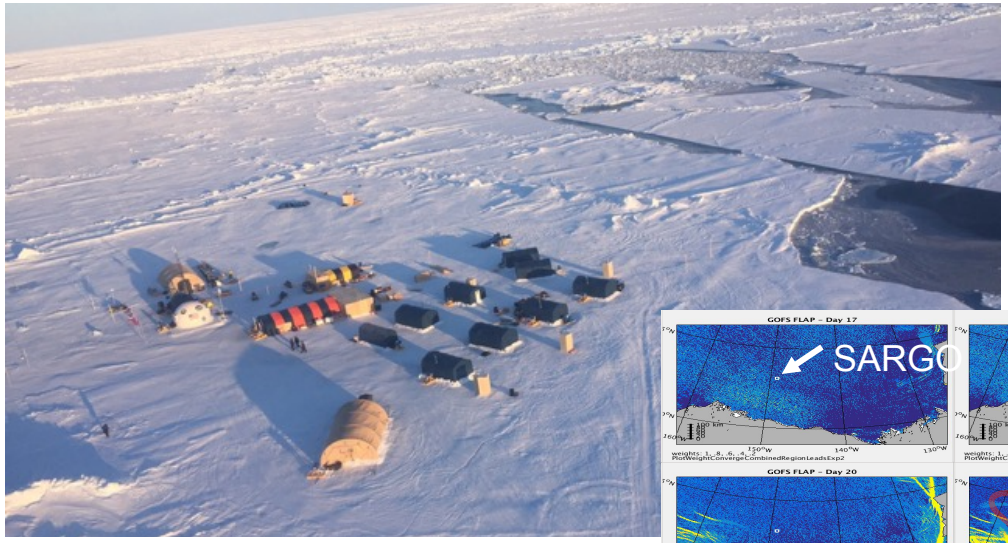
Products Used in Navy's Special Missions

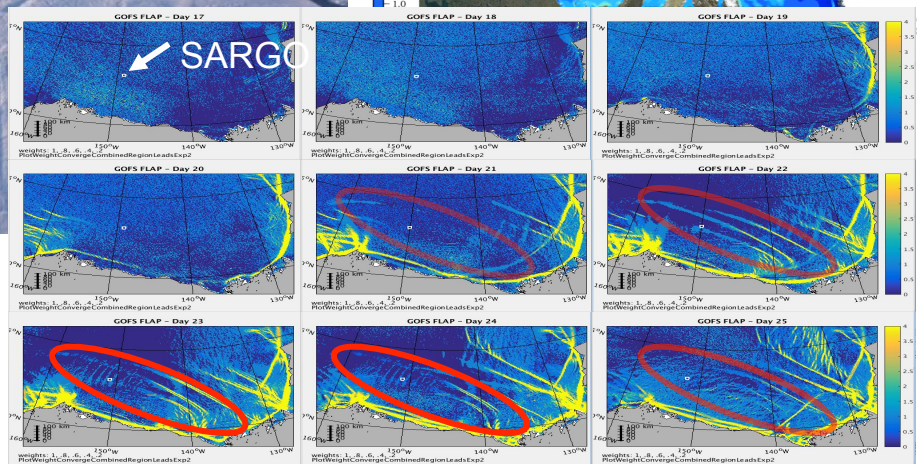
- Used as guidance in Nov/Dec 2011 convoy 103 M gallons of fuel to Nome, Alaska
- Used in pre-flight planning for NASA Operation IceBridge missions
- Used in ONR field experiments: Marginal Ice Zone (2014) and Sea State (2015)
- Used in Navy's ICEX field work

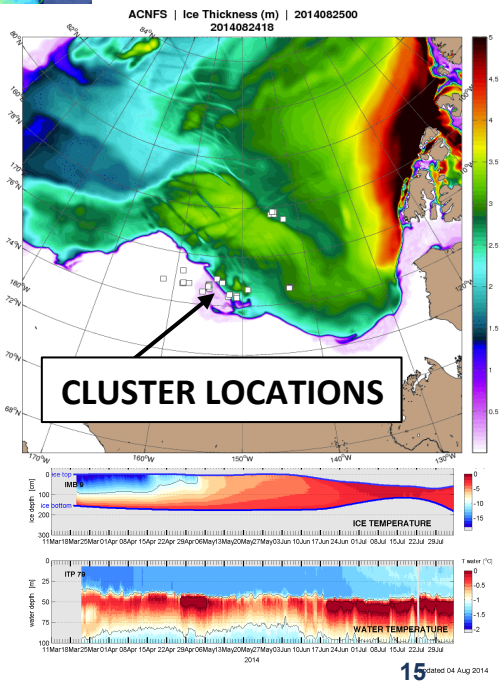












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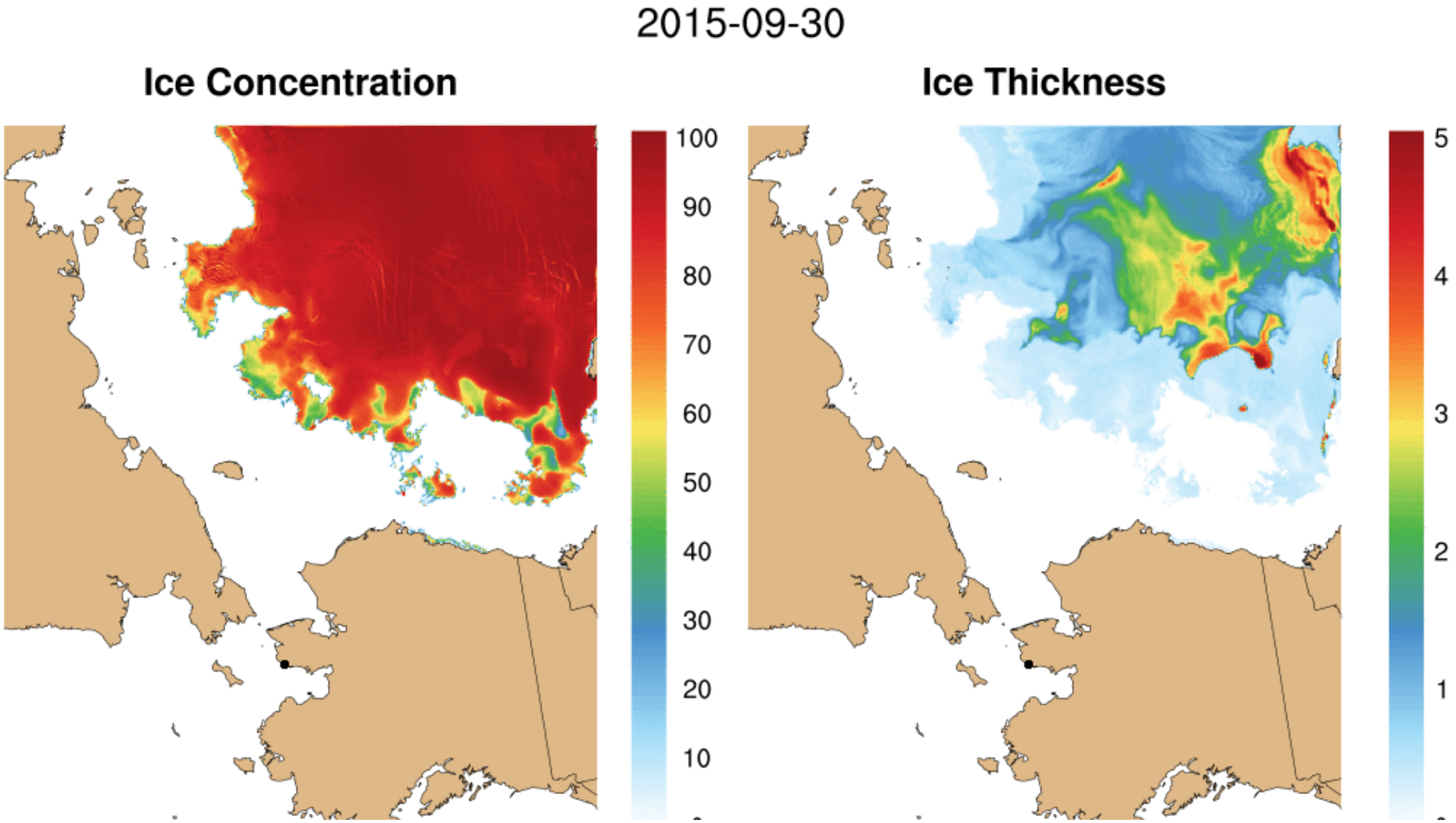
Regional CICE (2 km) Supported ONR Sea State Cruise (Oct 1 – Nov 15 2015)



Sikuliaq track shown in black

- Boundary conditions from GOFS 3.1
- Forced with daily 1) GOFS ocean fields and 2) 15 km COAMPS atmosphere

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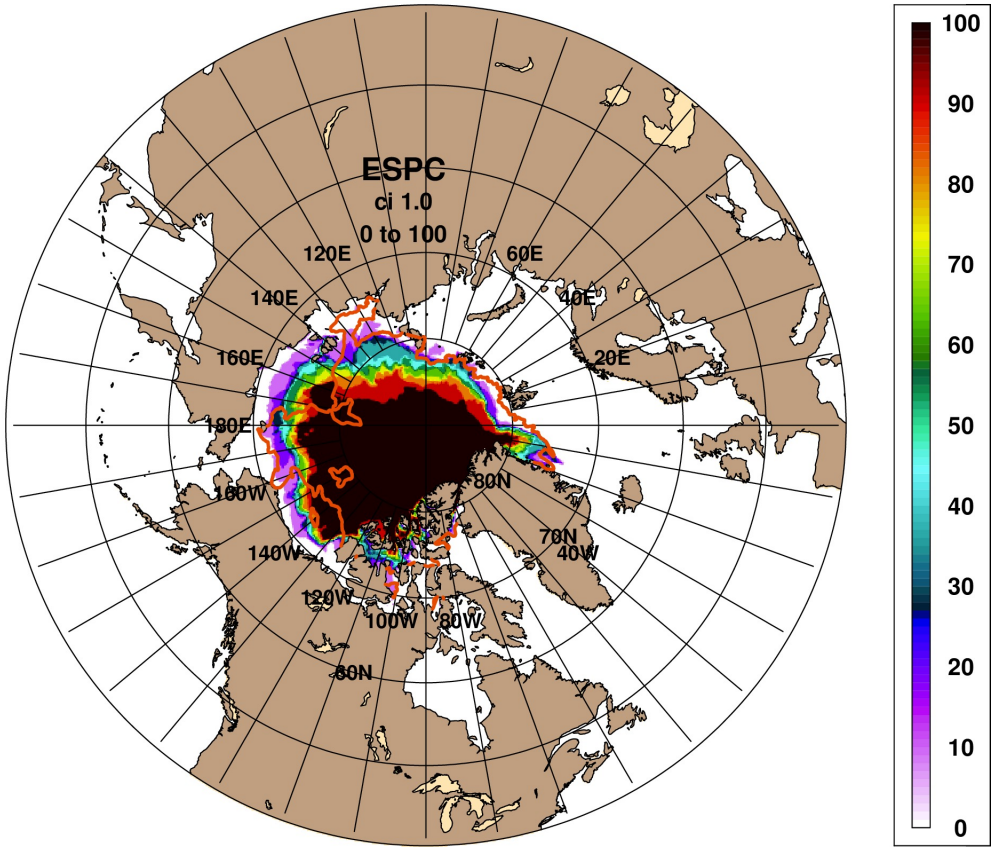
Sea Ice Prediction Network (SIPN)

- NRL has been a contributor to SIPN Sea Ice Outlook (SIO) since 2012

- Provided a 5-,4-, and 3–month forecast using fully coupled:
  - air/ocean/ice (ESPC)
  - ocean/ice (GOFS 3.1)

- Ensemble based using initial conditions (1 May, 1 June and 1 July 2016):
  - time-lagged ensemble
  - varied atmospheric forcing

Sea Ice Probability (%)



Sea Ice Probability (%) of the projected September 2016 mean ice extent from the Navy global atmosphere-ocean-ice coupled system. Red line is the NIC analyzed ice edge on 10 Sep 2016.

SIPN Sea Ice Prediction Network

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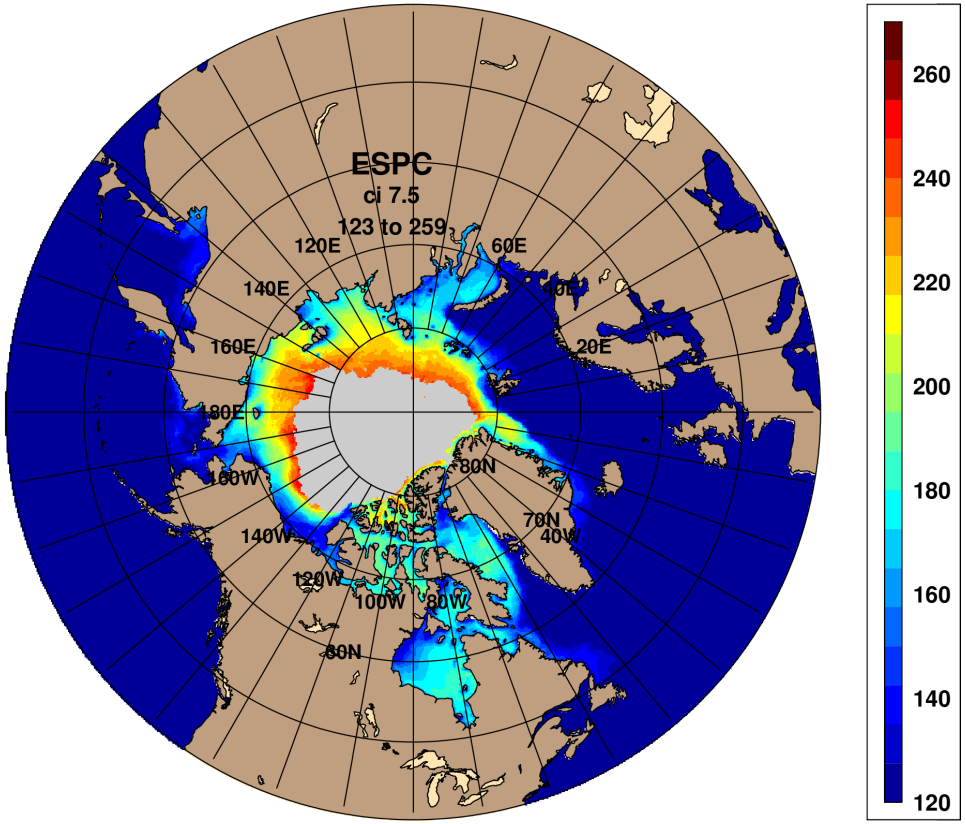
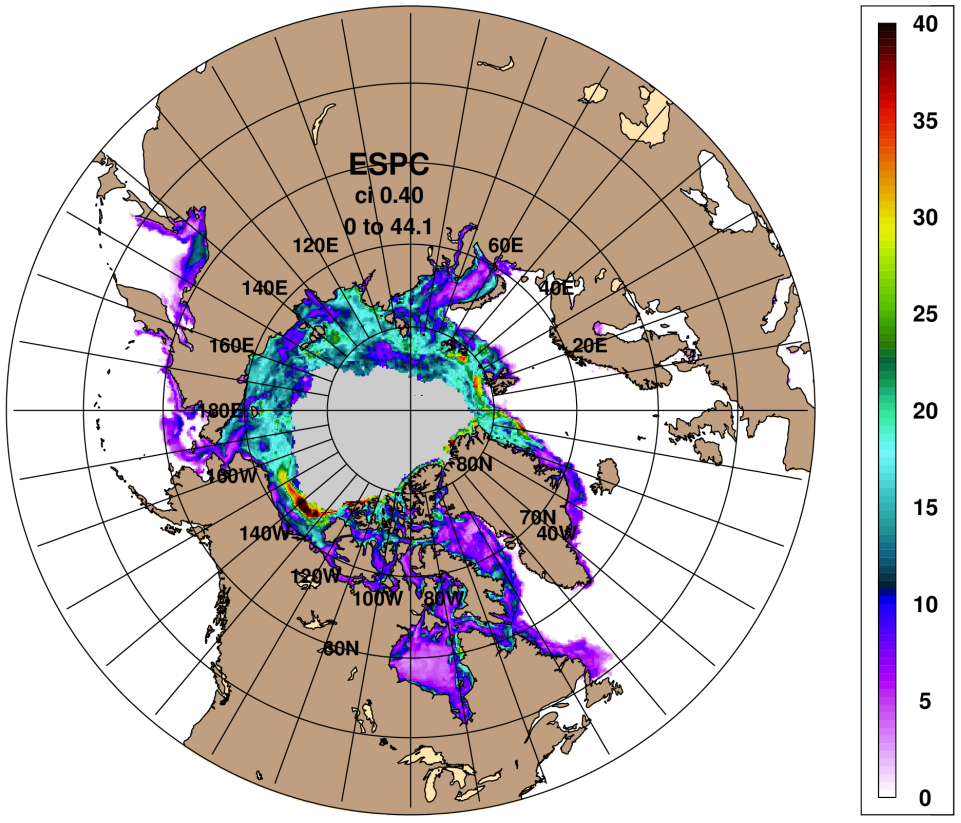
Sea Ice Prediction Network (SIPN)

Ice Free Date (IFD)



First ice-free ordinal date, with gray indicating a data void (i.e., no ice free days as the most likely outcome) from the Navy global atmosphere-ocean-ice coupled system 11 member ensemble.

Std. Dev. IFD



Standard deviation of first ice-free ordinal date, with gray indication a data void (i.e., no ice free days as the most likely outcome) from the Navy global atmosphere-ocean-ice coupled system 11 member ensemble.

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2016 Sea Ice Extent

NSIDC: 2016 Sept minimum ties with 2007 as the 2nd lowest sea ice extent, but ice growth has been faster than normal.

Forecast of the mean Sept sea ice extent using May 2016 ice conditions (SIPN Outlook effort)		
Observed NSIDC	ESPC (air/ocean/ ice)	GOFS 3.1 (ocean/ice)
4.72 Mkm^2 (mean)	4.8 Mkm^2 (4.4 – 5.3)	5.2 Mkm^2 (4.2 – 6.0)

Sept 2016 sea ice extent Minimum	
Observed NSIDC	Real-time GOFS 3.1
4.14 Mkm^2 (10 Sept 2016)	4.16 Mkm^2 (11 Sept 2016)

Sept 2016 sea ice extent Mean	
Observed NSIDC	Real-time GOFS 3.1
4.72 Mkm^2	5.07 Mkm^2

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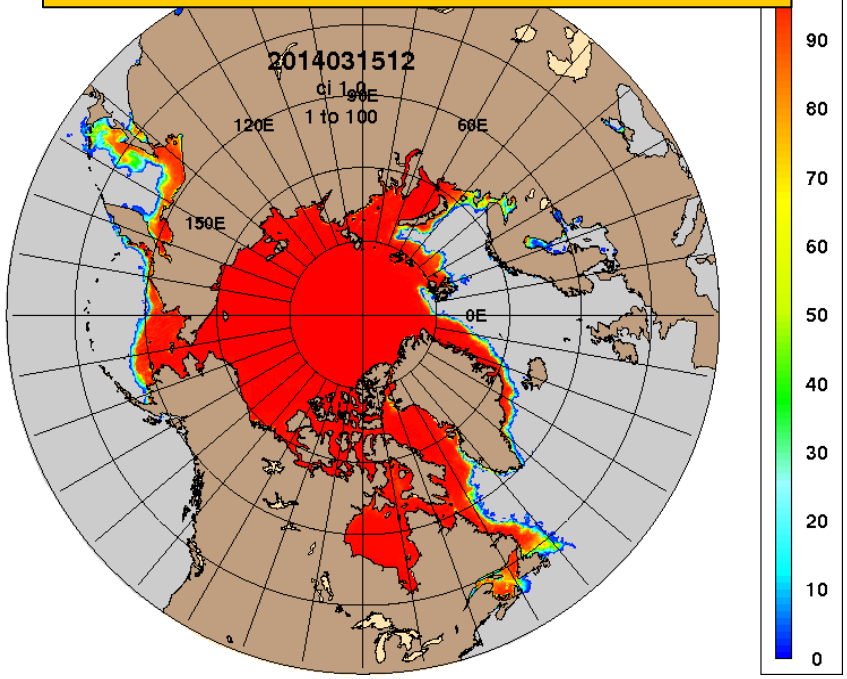
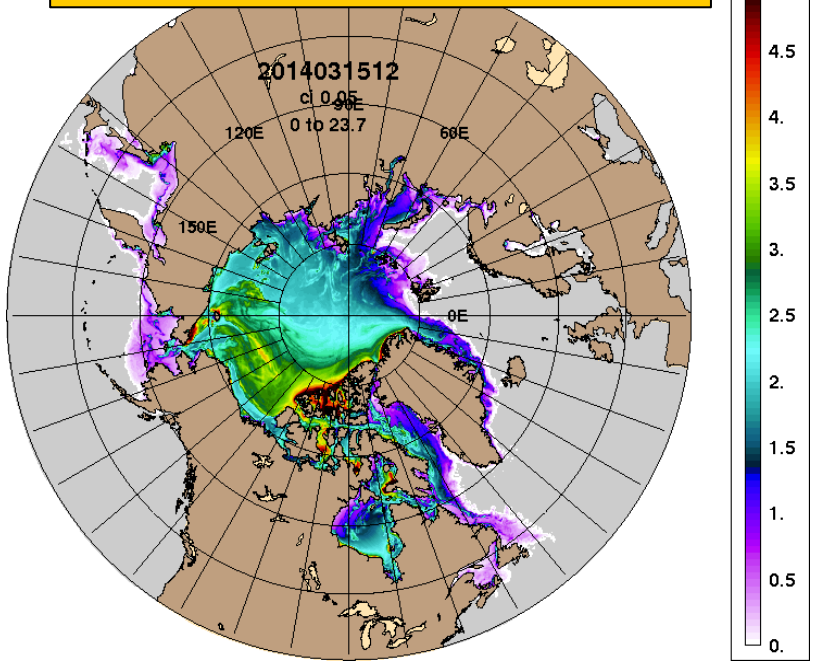
Future Operational Forecast Systems

- **NEXT GENERATION:** GOFS 3.5: 1/25^0 global two-way coupled HYCOM-CICE modeling system with data assimilation including tides
- Resolution 1.75 km at the North Pole (double resolution of GOFS 3.1)
- Early testing performed with CICE v4, operational product will use CICE v5 and will run in ESMF/NUOPC framework developed for ESPC
- Transition to NAVOCEANO scheduled for FY18

GOFS 3.5 Ice Concentration (%)
15 March 2014



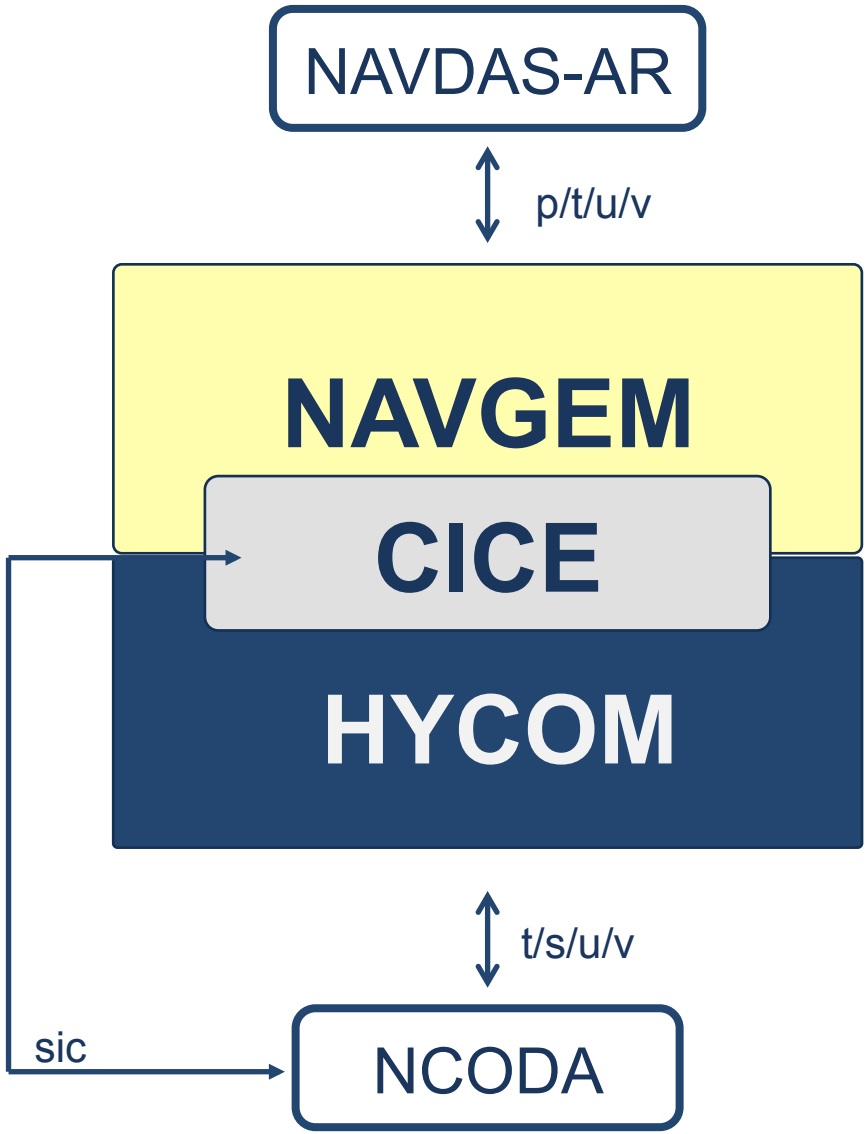
GOFS 3.5 Ice Thickness (m)
15 March 2014



Navy's Earth System Prediction Capability (ESPC)

- **Atmospheric Model:**
  - NAVy's Global Environmental Model (NAVGEM) (DoD)
  - Hogan et al. (2014), *Oceanography*
  - T359 horizontal resolution (~37 km)
  - 50 vertical levels
- **Atmosphere Data Assimilation:**
  - NAVDAS-AR
  - 4DVar
  - 6 hour update window
  - Rosmond and Xu (2005), *Tellus*
- **Ocean Model:**
  - HYbrid Coordinate Ocean Model (HYCOM) (DoD)
  - 0.08° (~9 km near equator, ~7 km at mid-latitudes)
  - 41 vertical hybrid layers
- **Sea Ice Model:**
  - Community Ice CodE (CICE) (DOE)
  - 0.08° (~3[illegible] at N[illegible])
- **Ocean/Ice Data Assimilation:**
  - NCODA
  - 3DVar
  - 24 hour update window
  - Cummings and Smedstad (2013) in *Data Assim for Atmos, Ocean & Hydro Applications*
- **Operational Capability:**
  - Initial Operational Capability in 2018
  - 16-day deterministic high resolution forecast every day
  - 30- to 45-day ensemble standard resolution forecasts
- **Rapid Development:**
  - Wave Watch III
  - CICE version 5
  - Aerosols
  - Coupled Data Assimilation

Same as GOFS 3.1



U.S. NAVAL RESEARCH LABORATORY

Future Plans and Technical CICE Challenges

Future Plans:

- Test/evaluate landfast ice routine from Jean-Francois Lemieux (Environment Canada)
- Test/evaluate new anisotropic rheology scheme. Will it be more appropriate for the FLAPs products?
- Test/evaluate column physic package
- Assimilation of additional satellite-derived and in-situ (ice thickness, snow, ice drift) measurements

Technical Challenges:

- With model resolution increasing, will the CICE physics still be appropriate?
- B- vs C-grid issues: HYCOM is on a C-grid. CICE's B-grid means that we must engineer all straits to be at least 2-grid points wide. We are not aware of any other issues due to this mismatch, but we would prefer a C-grid implementation

Thanks